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Exhaust Emissions from a Diesel Engine Fuelled by Diesel Fuel/RME Blends

Abstract: Rapeseed Methyl Esters (RME) are becoming more and more common as a fuel for diesel engines. Advantageous effects of RME on exhaust emissions from older diesel engines have been confirmed in many previous studies. However, in case of modern engines, the influence of RME on exhaust emissions seems to be less recognized and evident. The aim of the research described in this paper was to evaluate the potential of RME as a liquid fuel for modern diesel engines in relation to meeting emissions requirements.

The tests were carried out at the Poznan University of Technology's Emissions Testing Laboratory using the AMX-210/100 engine test bed. The SENSORS SEMTECH-DS exhaust gas analyzer (CO, HC and NO_x emissions) and AVL Micro Soot Sensor and Smoke Meter (PM emissions) were used to measure exhaust emissions. The emission measurements were carried out over the 13-mode ESC cycle. The tests were conducted on a direct injection (common rail), turbocharged, passenger car diesel engine, representing Euro 4 emissions level. Four different diesel fuel/RME blends were tested. These blends contained respectively: 20, 50 and 100% RME. The main result of RME application was significant reduction in HC and PM emissions, accompanied by only a slight increase in NO_x emissions.

Key words: *diesel engine, exhaust emissions, biofuel, RME*

Emisja szkodliwych składników spalin przez silnik ZS zasilany mieszaninami oleju napędowego i RME

Streszczenie: Estry metylowe kwasów tłuszczowych oleju rzepakowego (RME – ang. Rapeseed Methyl Esters) stają się coraz powszechniej stosowanym paliwem do silników o zapłonie samoczynnym. Korzystny wpływ RME na toksyczność spalin silników ZS starszego typu został wykazany w wielu pracach badawczych. W zakresie nowoczesnych silników, wpływ RME na toksyczność spalin jest mniej poznany. Celem badań opisanych w niniejszej pracy było określenie potencjału RME w zmniejszaniu toksyczności spalin nowoczesnych silników o zapłonie samoczynnym.

Badania wykonano w Laboratorium Toksyczności Spalin Politechniki Poznańskiej na hamowni silnikowej AMX-210/100. Pomiarów toksyczności spalin dokonano z wykorzystaniem analizatorów spalin: SEMTECH-DS firmy SENSORS INC. (pomiar stężenia CO, HC i NO_x) oraz AVL Micro Soot Sensor i Smoke Meter (pomiar zawartości PM). Pomiary odbywały się w teście ESC (ang. European Stationary Cycle), na silniku ZS o wtrysku bezpośrednim, doładowanym turbosprężarką, zasilanym w systemie common rail i spełniającym normę emisji spalin Euro 4. W badaniach stosowano cztery paliwa: olej napędowy (ON) i RME (B100) oraz ich mieszaniny B20 i 50, zawierające odpowiednio 20 i 50% RME. Efektem zastosowania RME było przede wszystkim istotne zmniejszenie emisji HC i PM przy niewielkim wzroście emisji NO_x.

Słowa kluczowe: *silnik ZS, emisja spalin, biopaliwo, RME*

1. Introduction

Since the 1980s of the last century the ecological aspects have been the most important factors stimulating the advancement of vehicle powertrains and fuels. A huge advancement in the area of fuels did not at all change the fact that crude oil remains a dominant source of motor fuels. It is a slow but steady process, however that the share of biofuels grows in the fuel market. In the European Union it is mostly due to the EU policy in this matter (Directive 2009/28/EU and earlier 2003/30/EU) as well as the policies of the individual member states. In Poland, the development of the fuel market is instituted by "The long-term biofuel or other renewable fuel promotion scheme for the years 2008–2014" adopted by the resolution of the Council of Ministers in 2007. This scheme imposes on the fuel producers and distributors regular annual boosting of the biofuel share in the fuel market. Non-compliance with the scheme results in serious financial penalties borne by the responsible entities.

Currently, we have no doubt that the renewable fuels market will develop. This results not only from the previously mentioned legal acts but also crude oil prices maintained on a high level and the greenhouse effect, not to mention other significant factors. In the EU the most important renewable fuel is FAME (Fatty Acid Methyl Esters), manufactured mainly in the form of RME (Rapeseed Methyl Esters). The EU is also the largest manufacturer of this fuel (fig. 1). It is assumed that the scale of production and consumption of this fuel will continue to grow due to a growing demand for diesel fuels and a stable demand for gasoline. Currently, conventional diesel fuels contain FAME in an amount of up to 7%. The consumption of FAME in its pure form grows rapidly as well. In Poland it is mainly caused by its reasonable pricing, approximately 20% lower than the conventional diesel fuel.

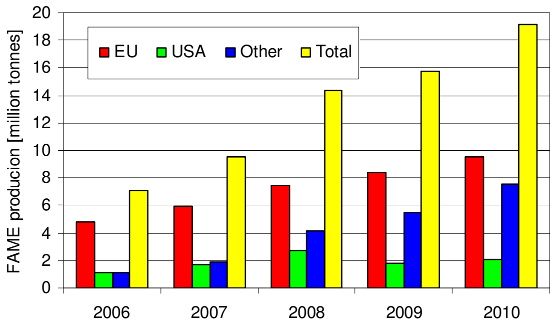

Fig. 1. Production of FAME since 2006 with forecast for 2010 [1]

Even though the use of renewable fuels (biofuels in particular) chiefly aims at protecting the natural resources, reduction of CO_2 and deliverance from the necessity to exploit fossil fuels, their application also positively influences the exhaust emissions, hence reduces air pollution. The use of FAME in its pure form or as an additive significantly influences the exhaust emission level of diesel engines. There is much published literature devoted to this issue [2–9]. Lauperta and his associates [10], based on the analysis of almost 160 scientific works in this matter concluded that the application of FAME most frequently results in: a reduction of CO, HC and PM and a growth of the emission of NO_x (fig. 2).

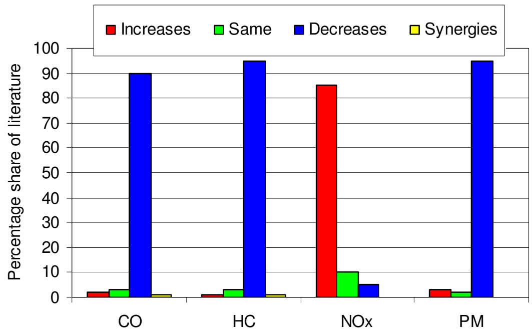

Fig. 2. Estimated percentage share of literature reporting decreases, similarities or increases in the exhaust emissions using FAME as diesel fuel [10]

We should note, however that the majority of the investigations related to FAME were performed on older engines (conventional injection systems). This results from a dynamic advancement of the diesel engines in recent years (significant increase in the injection pressure, downsizing etc.). What is more, many investigations focus on the measurement of the emission at only some selected points of engine run, which gives a limited perspective on the influence of FAME application on the exhaust emissions in the whole area of engine operation. The above mentioned facts constituted the basis for the investigations presented in this paper. The investigations comprised the measurement of the exhaust emissions from a modern diesel engine fueled with diesel fuel, RME and blends of both of these fuels for comparison. The tests were performed under the conditions of the ESC homologation test.

2. The test stand and the test conditions

The investigations presented in this paper were conducted on an engine test stand by Automex, fitted with an AMX-210/100 eddy current brake. The tests utilized a diesel engine representing the current state of technological advancement in this type of engines. The technical data of this engine have been shown in table 1. The exhaust emissions tests were performed under the conditions of the ESC (European Stationary Cycle) homologation procedure. During the tests the engine was fueled with a diesel fuel (DF) and RME (B100) of properties shown in table 2 as well as the blends of the above fuels: B20 (20% RME and 80% DF) and B50 (50% RME and 50% DF). While composing the B20 and B50 fuels the authors took into account that diesel fuel contained 4.9% FAME.

Table 1. Specifications of the test engine

Engine type	Diesel, 4-cylinder in-line
Displacement	1.251 dm^3
Max. power	51 kW @ 4000 rpm
Max. torque	180 Nm @ 1750 rpm
Injection/Combustion type	Direct injection, common rail, turbo-charged (intercooled)
Number of valves	4 per cylinder
Max. injection pressure	140 MPa
Fuel dose split	up to 4 injections per stroke
Exhaust gas recirculation	Electronically controlled (closed-loop)
Emission control	Oxidation catalyst
Calibrated to	Euro 4

Table 2. Diesel fuel (DF) and RME specifications

		Unit	DF	RME (B100)
Cetane number		–	52.6	51.0
Cetane index		–	52.8	–
Density @ 15°C		kg/m^3	833.5	883.0
Viscosity @ 40°C		mm^2/s	2.66	4.46
Sulfur content		ppm	9.9	0.8
Fatty acid methyl esters content		% (v/v)	4.9	98.5
Polyaromatic hydrocarbons content		% (m/m)	2.5	–
Iodine number		g I/100 g	–	115
Distillation	E250	% (v/v)	39.0	–
	E350	% (v/v)	94.5	–
	T95	°C	350.6	–

The exhaust uptake for analysis took place before the catalyst. For the measurement of the exhaust components a SEMTECH-DS analyzer by SENSORS INC. (fig. 3) was used. The analyzer measured the exhaust components (CO, HC, NO_x) and mass flow of the exhaust gases. For the measurement of PM a Micro Soot Sensor by AVL was used. It measures the PM concentration in the range of 0–50 mg/m^3, with the use of the photo-acoustic method (PASS – Photo Acoustic Soot Sensor). The analyzer was fitted with the exhaust conditioning system (both temperature and air dilution). For the measurement of the FSN filter opacity, soot concentration C and exhaust gas opacity N a Smoke Meter by AVL was used. This allowed a continuous measurement of the exhaust gas opacity at the same time calculating the rest of the parameters.

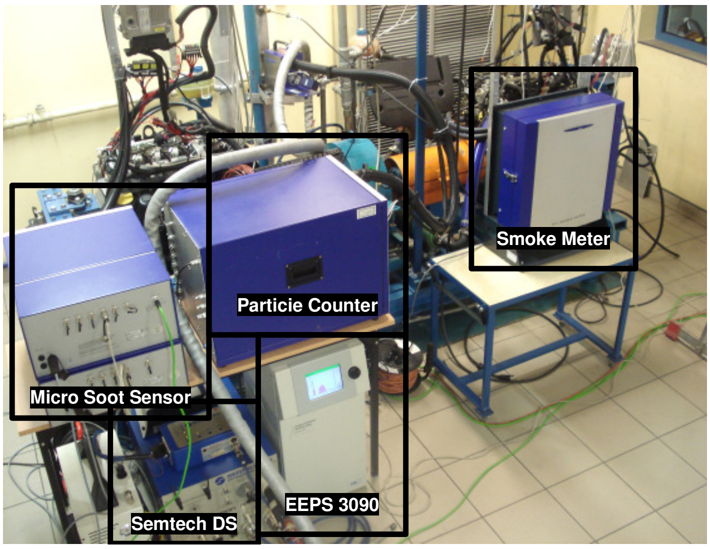

Fig. 3. The view of the engine test bed with the research equipment

3. The results and discussion

Fueling of a combustion engine with fuel containing RME brings measurable benefits in the form of a reduction in hydrocarbons (HC) emissions. The performed tests disclosed a significant drop in the HC emissions in each mode of the ESC test and the emission calculated for the whole test (fig. 4). When analyzing the influence of individual fuels (different RME content) on the HC emissions, we can see that the reduction of the said emission is proportional to the RME content, hence the reduction is the highest for B100 (by 42% in the whole ESC test). It is a good result, though, according to EPA [11], the average reduction of the HC emissions when using pure FAME reaches 70%.

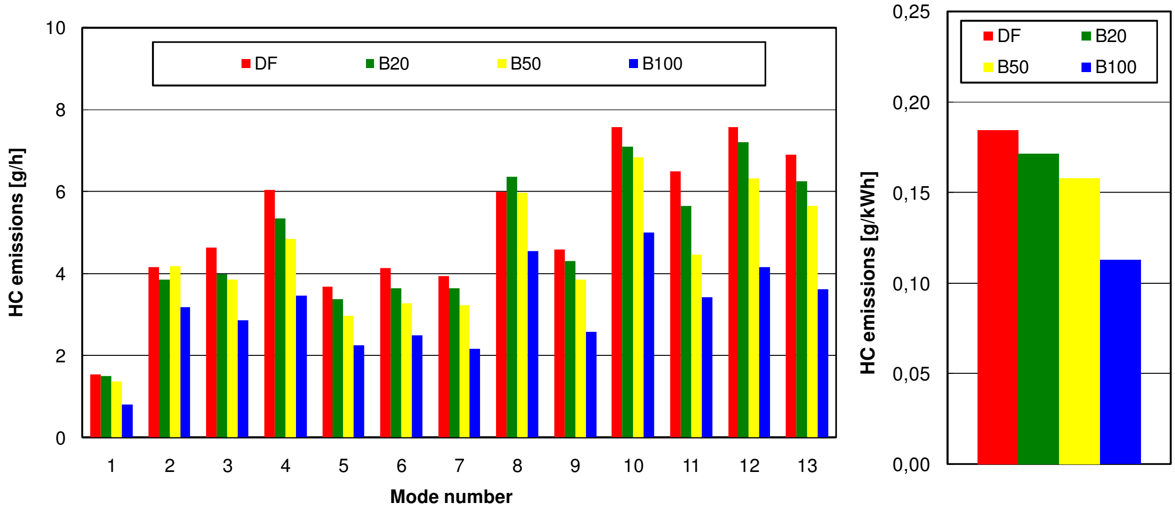

Fig. 4. HC emissions: in individual ESC test modes (left) and in the whole ESC test (right)

In light of the advantageous impact of RME on the HC emissions, a little surprising was the influence of this fuel on the carbon monoxide (CO) emissions (fig. 5). Except mode 10, a growth of the emission of CO was recorded for fuels containing RME. It is also worth noting that the differences in the CO emissions among fuels of different RME content are in many modes (5, 6, 7, 9, 11, 12, 13) miniscule. Finally, for the whole ESC test for fuels containing RME an increase in the CO emissions was obtained (the lowest for pure RME i.e. B100). Within the fuels containing RME, its increased content resulted in a drop in the CO emissions, which is in line with the result of other investigations. A fact that is different from the majority of the investigations described in literature is a higher level of CO for fuels containing RME as opposed to diesel fuel. According to EPA [11], there is almost a linear relation between the CO emissions and FAME content. On average, for pure FAME, they obtained almost a 50% reduction in the CO emissions.

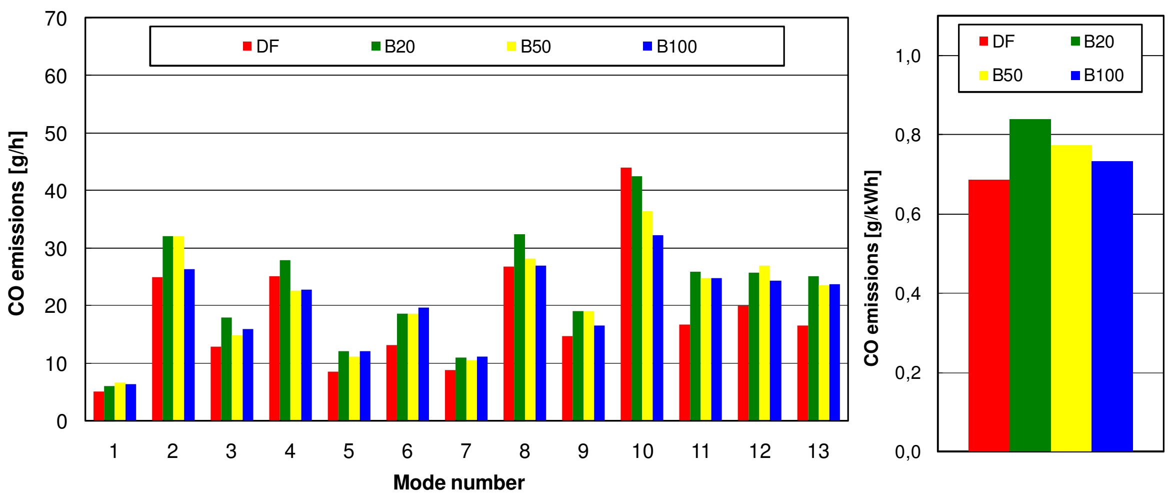

Fig. 5. CO emissions: in individual ESC test modes (left) and in the whole ESC test (right)

The application of fuel containing RME resulted in an increase in the emission of NO_x (fig. 6). Such an influence of RME is also described in the majority of the published research results. We also need to state that the recorded increase in the emission of NO_x caused by RME is miniscule – does not exceed 5%. In light of the EPA data [11], confirming that the fueling with pure FAME causes, on average, a more than 10% increase in the NO_x emissions, the results obtained within the investigations described here can be deemed as advantageous. This could be supported by the fact that in the modes of the highest NO_x emissions rate (modes of the highest load) the emission of NO_x for B100 is lower than in the case of diesel fuel.

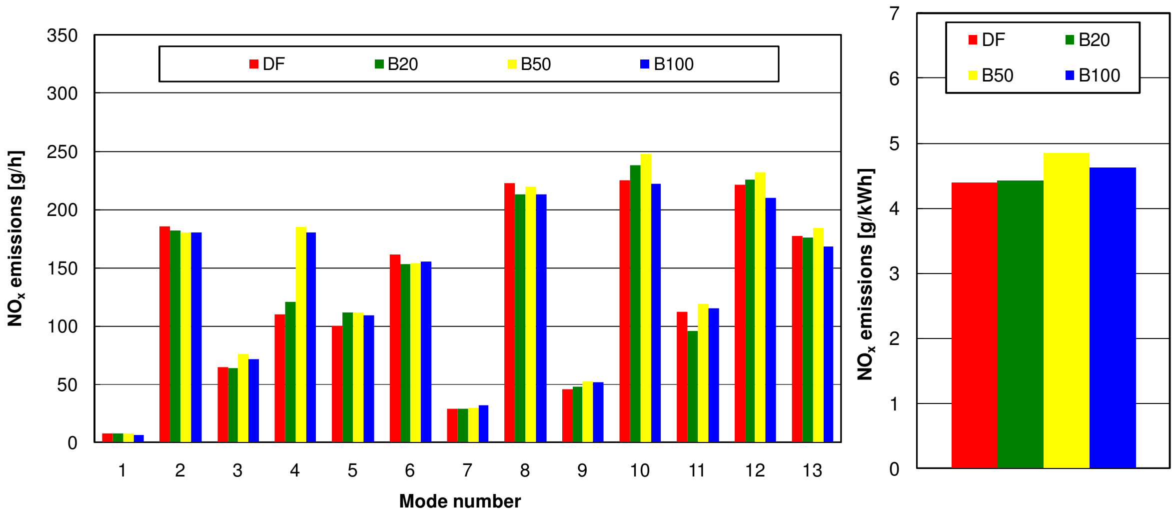

Fig. 6. NO_x emissions: in individual ESC test modes (left) and in the whole ESC test (right)

Based on the measurement results the authors also calculated the emission of particulate matter. Beside the emission in the individual modes of the ESC test expressed in g/h, the emission of PM was calculated for the whole test expressed in g/kWh (fig. 7).

The analysis of the PM emissions in individual modes of the test leads to a conclusion that the addition of RME in the diesel fuel has a significant impact on the reduction of PM in the engine exhaust. Along the growth of the percentage share of RME in the fuel, the PM emissions clearly reduces. This is particularly visible in the case of the high value of the main engine parameters (engine speed and load).

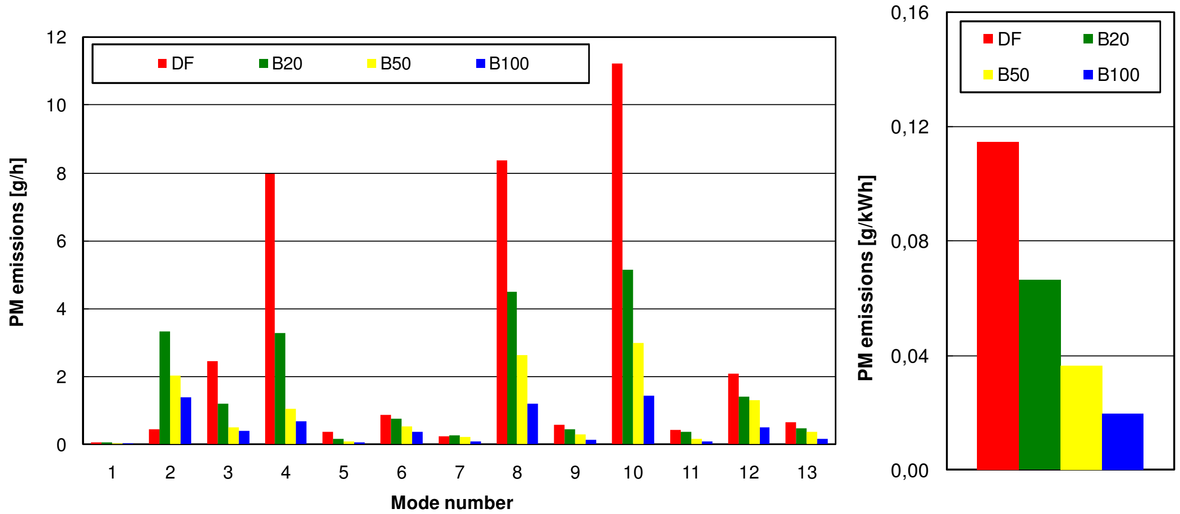

Fig. 7. PM emissions: in individual ESC test modes (left) and in the whole ESC test (right)

Pure RME (B100) is characterized by a very small PM emissions. For all the test modes it does not exceed 1.5 g/h. Particularly interesting seems the comparison of the PM emissions for diesel fuel and pure B100. In some case (for the test modes of high engine speed and maximum load) a difference in the hourly emission of up to 88% was obtained. The unit emission (calculated of the whole ESC test) was approximately 83% lower when fueled with B100. These values are more advantageous than those given by EPA [11], where an approximately 50% PM reduction is assumed for pure FAME. A confirmation of the significant reduction of PM, when using RME, is also the results of the smoke emissions tests shown in figure 8.

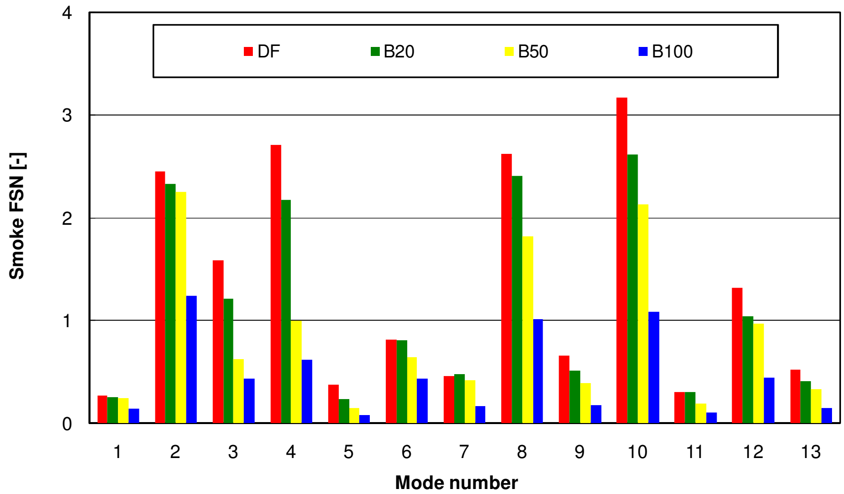

Fig. 8. Smoke FSN in the individual ESC test modes

Figure 9 presents the fuel consumption of a test engine fueled with diesel fuel and B20, B50 and B100 in the ESC test. As we can see, a small increase in the fuel consumption took place, proportional to the RME content. For pure RME this increase amounts to 9%. The observed increase in the fuel consumption is proportional to the lower calorific value of the fuel containing RME and proves the same engine efficiency for all the tested fuels.

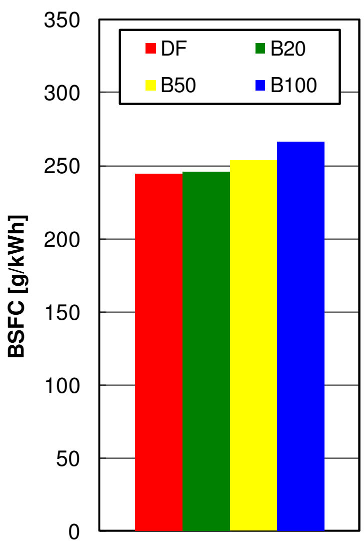

Fig. 9. Fuel consumption in the ESC test

4. Conclusions

- The performed tests have shown significant impact of RME as a fuel component on the exhaust emissions from a modern common rail turbocharged diesel engine.
- The emission of HC in the ESC test decreased as the RME content in the fuel grew and was the lowest for pure RME (B100).
- The emission of CO in the ESC test was higher when fueled with fuels containing RME, yet, as the RME content grew this emission dropped. For pure RME the authors obtained a result similar for the diesel fuel (6% difference). We should note that CO is the east troublesome exhaust component due to its efficient afterburning in the oxidation catalyst.
- The emission of NO_x in the ESC test grew slightly (several per cent maximum) for fuels containing RME, which was an expected effect of the application of this biofuel.
- The emission of PM in the ESC test reduced very significantly for the fuel containing RME. The reduction in the PM emissions was proportional to the RME content in the fuel. For pure RME an almost 6 time lower PM emissions level was recorded as opposed to the diesel fuel.
- The use of RME did not have an effect on the engine efficiency – the growth in the fuel

consumption was proportional to the lower calorific value of fuel containing RME.

– The influence of RME on the exhaust emissions from a modern diesel engine in the ESC test is evaluated as positive. This is indicated by a high reduction in the HC emissions and a high reduction of the PM emissions in particular at a very insignificant growth of the emission of NO_x. In light of the performed tests, the most advantageous is the use of pure RME (B100) in terms of the exhaust emissions.

Abbreviations

EPA Environmental Protection Agency
ESC European Stationary Cycle
FAME Fatty Acid Methyl Esters
RME Rapeseed Methyl Esters

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